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# FILTERING OF ACCELERATORY SENSOR'S MEASURING SIGNAL AND PIEZO-GYROSCOPE WITH CHEBYSHEV FILTER

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**ABSTRACT:** Increasing of acting frequency of power steering systems in cars causes the difficulties in registering of phenomena proceeding between tire and roadway. Modern sensors give new measuring possibilities, including in their range the frequencies caused by the above mentioned appliances. Increasing of measurements frequency causes increasing of registered signals' noises, limiting signals' legibility. Usage of signal filtration multiplies legibility of accelerations signals and limits to minimum losing of essential data contained in the signal.

In this paper there is described the influence of filtration with Chebyshev filter of 4-th and 6-th orders on accuracies of car movement parameters measurements carried out with acceleration sensors and piezo-gyroscopoe. Road tests were verified by measurements of path traveled by car and its instantaneous speed. There were carried out the signals statistical analysis and determined measuring accuracy of designed appliance basing on comparison of measured path, speed and acceleration values.

**KEY WORDS:** measurement accuracy, measuring signal filtering, digital filters, measuring apparatus, car movement kinematics.

## 1. INTRODUCE

Within framework of cooperation of Institute of Forensic Research in Kraków and Chair of Basics of Machine Design of Poznań University of Technology there were designed and manufactured the integrated sensors module (ISM) based on acceleration microchips and piezo-gyroscope.

Acceleration sensors are made in technique iMEMS (integrated Micro Electro Mechanical System) with accelerations sensor in which inertial mass, reacting to acting input function, changes the capacitor's capacity and generates proportional voltage signal [2, 11]. And piezo-gyroscope by piezo-element distortion generates voltage reflecting angular velocity to which sensor is subjected [11].

Making use of acceleration sensors and piezo-gyroscope, for determining of vehicle movement kinematical properties [5, 6, 7, 8, 9], involved determining their measuring accuracy. Quantitative assessment of found braking process characteristics were done by verification of these characteristics with additional measurements, length of traveled by vehicle path and by vehicle speed value in given time interval.

Measuring system, besides ISM, includes the card A/C cooperating with software for data archiving and enabling archiving them with given frequency up to 1000 Hz. Increasing of measuring frequency causes increasing of evident noises leading to loosing of acceleration characteristics legibility during road tests. There was taken trial of counteraction against those phenomena using digital filters. And there was checked the influence of digital Chebyshev filter 4-th and 6-th order and Kalman filter described in [7].

In this paper there is described method of experimental verification of vehicle movement kinematical characteristics determining and influence of Chebyshev filter on measurement accuracy.

## 2. EXPERIMENTAL VERIFICATION

Measuring accuracy ISM was determined experimentally carrying out road tests of intensive braking car equipped with ABS system. Evaluation of designed device measuring accuracy was carried out by verification of traveled path and speed between characteristic points. Measuring set consists of photocell assembled on the vehicle, which enables to determine the time interval of vehicle traveling between two reflective strips located along traveled path, enabling to determine average speed value on measuring interval. Reflective strips, of which passing by photocell is registered in time function as a binary event, are the characteristic points enabling carrying out the measurement of traveled path on interval L, that is from reflective strip to the place of stopping. Interval L measured with measuring tape is compared to the path calculated basing on temporary accelerations.

## 3. STATISTICAL ANALYSIS

Carried out automobile intensive braking tests were fully archived on computers disk, what enabled making the car breaking process analysis and comparison of the path traveled by vehicle with the path calculated basing on acceleration course.

All carried out measuring tests were made subject of statistical analysis. Sensors exploited in the measuring system generate analogous voltage signal on output proportional to acting input function, and this signal is subjected to quantization, sampling and digitizing with given measuring frequency. Uncertainness of designed measuring system particular elements cause increasing of voltage signal errors generating additional voltage [4]. Measuring process and process of analog-to-digital cause the increasing of voltage signal value, decreasing its legibility by manifestation of measuring noises. Vehicle deceleration characteristic without using of digital filters is shown in drawing 1.

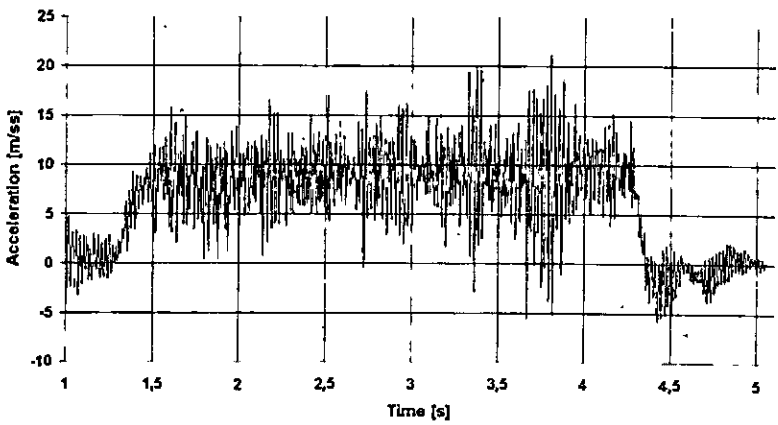


**Fig. 1:** Course of vehicle deceleration during braking process without using of digital filters

Carried out statistic analysis consisted in determining of standard deviation for as single measurement of vehicle traveled path. Path measurements done with measuring tape were treated as pattern without any error. Determining of traveled path from registered accelerations run and angles of the car body turn are carried out by double digital integration [1] of found signal.

For results got from measuring tests, standard deviation of single measurement for found results was $\sigma_S$ = 0.15 [m], and after applying corrections according to t-Student's distribution for 10 measurements and for confidence level of 95 % error of traveled path determining was $\sigma_S$ = 0.34 [m].

Also vehicle temporary speeds got in given time moment were subjected to comparison. Determined standard deviation for single measurement was $\sigma_V$ = 0.27 [m/s], and maximum relative

error was $\Delta_V = 2.3$ %. After applying corrections for t-Student distribution for 10 measurements and confidence level of 95 % it was $\sigma_V = 0.62$ [m/s]. All results of measuring series were subjected to test for occurrence of excessive error using Chauvent's method. In any measuring series there was no gross error.

Experimentally determined accuracy of ISM was a pattern in analysis of digital filters influence on measurements results.

## 4. CHEBYSHEV FILTER

Signals generated by measuring sensors, written on computer disc in discrete form, after attributing of value in process of signal transformation in card A/C, have units of measured value and are charged with measuring noises (drg. 1). Tapering of deceleration run found during tests consists in elimination of components of higher frequencies using digital filters and its task is eliminating of noises influence on vehicle movement kinematic characteristics values.

For limiting of influence of high-frequency signal fluctuations there was used digital Chebyshev filter 4-th and 6-th orders [3, 10]. Applied filter is a low-pass filter and is characterized with wavy characteristic in pass band, flat characteristics in barrier band and with higher steep of characteristics than Butterworth filter described in [3].

Defining Chebyshev filter there is given its order, limit frequency and range of characteristic oscillation in pass band. For applied Chebyshev filter there was taken pass characteristics oscillation range on level of 0,1 dB. Example accelerations characteristics runs found after filtration with Chebyshev filter are shown in drawings 2 and 3, while results of carried out numerical tests are given in tables 1, 2 and 3.

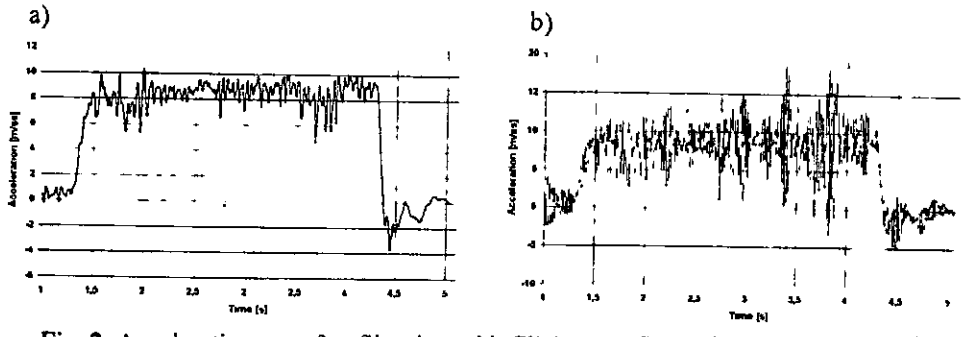


**Fig. 2.** Acceleration run after filtration with Chebyshev filter of 4-th order for limit frequency a) 20 Hz and b) 40 Hz

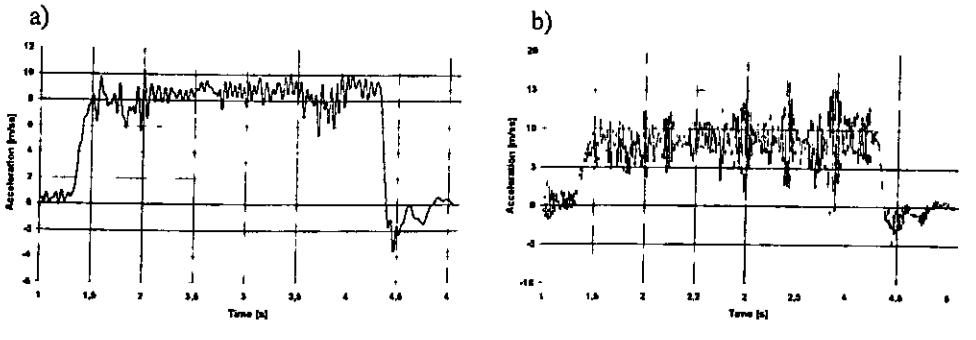


**Fig. 3:** Acceleration run after filtration with Chebyshev filter of 6-th order for limit frequency, a) 20 Hz and b) 40 Hz

Presented in drawings 2 and 3 acceleration run subjected to filtration with Chebyshev filters of 4-th and 6-th order are characterized with significant evident lowering of measuring noises. Lowering of filter limit frequency causes increasing of measurements legibility and lowering of indications accuracy.

**Table 1.**

| Standard deviation for single measurement of traveled path | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ISM without filtration [m] | For Chebyshev filter of 4-th order for limit frequency in [m] | | | | | For Chebyshev filter pf 4-th order for limit frequency in [m] | | | | |
| | 100 [Hz] | 50 [Hz] | 40 [Hz] | 30 [Hz] | 20 [Hz] | 100 [Hz] | 50 [Hz] | 40 [Hz] | 30 [Hz] | 20 [Hz] |
| 0,15 | 0,15 | 0,15 | 0,16 | 0,20 | 0,30 | 0,15 | 0,21 | 0,27 | 0,37 | 0,59 |

**Table 2.**

| Standard deviation for single measurement of speed | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ISM without filtration $V_{ZMC}$ [m/s] | For Chebyshev filter of 4-th order for limit frequency in [m/s] | | | | | For Chebyshev filter pf 4-th order for limit frequency in [m/s] | | | | |
| | 100 [Hz] | 50 [Hz] | 40 [Hz] | 30 [Hz] | 20 [Hz] | 100 [Hz] | 50 [Hz] | 40 [Hz] | 30 [Hz] | 20 [Hz] |
| 0,27 | 0,28 | 0,26 | 0,25 | 0,24 | 0,23 | 0,26 | 0,23 | 0,23 | 0,22 | 0,25 |

**Table 3.**

| Standard deviation for single measurement of acceleration | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| For Chebyshev filter of 4-th order for limit frequency in [m/s$^2$] | | | | | For Chebyshev filter pf 4-th order for limit frequency in [m/s$^2$] | | | | |
| 100 [Hz] | 50 [Hz] | 40 [Hz] | 30 [Hz] | 20 [Hz] | 100 [Hz] | 50 [Hz] | 40 [Hz] | 30 [Hz] | 20 [Hz] |
| 0,060 | 0,049 | 0,044 | 0,034 | 0,019 | 0,051 | 0,033 | 0,023 | 0,015 | 0,034 |

## 5. SUMMARY

Measurements of vehicle accelerations with integrated sensors module enable for determining of braking process kinematic properties with uncertainty below 2.3%. These measurements of accelerations, referring to their transformations from analog form to digital form which they are subjected, are burdened with errors caused by these transformations, and this causes generating of excessive voltage signal and generating of noises of big amplitude (see drg. 1). Applying of low-pass Chebyshev filter causes decreasing of vales spread around the expected value and increasing standard deviation value for single measurement for determining of traveled path by vehicle. Chebyshev filter lowers standard deviation value of determining vehicle accelerations and speed on checking interval, but the differences in deviation for speed are negligible. Applying of signal filtering for determining kinematic properties of vehicle movement is limited because of necessity of using small limit frequency and because of essential standard deviation increase during increasing legibility of acceleration characteristic.

Beside of described Chebyshev filter, for legibility increasing of found experimental acceleration characteristics there was applied Kalman filter described in article under title „Measuring signal filtration of acceleration sensor set and piezo-gyroscope with Kalman filter" [7].

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